The impact of renal insufficiency on the outcome of carotid surgery is influenced by the definition used

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Background: **Renal insufficiency (RI) seems to be a source of complications after carotid endarterectomy (CEA). However, published studies do not use a common definition of RI. Our objective was to analyze the effects of RI on carotid surgery using three classifications of renal function.**

Methods: **Using a prospective database, we studied renal function and postoperative complications in patients operated on between January 1, 2003 and December 31, 2008. Renal function was studied using the level of plasma creatinine, creatinine clearance calculated according to the Cockcroft formula, and to the Modification of Diet in Renal Disease (MDRD) equation. For each method, the patients were divided into three groups: normal renal function, moderate RI, and severe RI. The principal judgment criterion was the 30-day non-fatal stroke and death rate.**

Results: **The analysis concerned 961 CEAs carried out in 901 patients. The 30-day non-fatal stroke and death rate was 2%. In the analysis of renal function using the level of creatinine, there was no statistical difference between the groups in the 30-day stroke and death rate (normal renal function: 1.8%, moderate: 2.7%, severe: 8.3%, $P = .21$). The analysis of renal function according to creatinine clearance calculated using the Cockcroft formula showed that in the severe RI group, the stroke and death rate was higher than in the other two groups (normal renal function: 1.7%, moderate RI: 1.4%, severe RI: 7.5%, $P = .004$). Analysis using the MDRD formula showed similar differences between the severe RI group and the other two with a higher rate of 30-day stroke and death (normal renal function: 1.4%, moderate RI: 1.7%, severe RI: 12.5%, $P < .001$). Subgroup analysis showed that among patients with severe RI according to the creatinine clearance, those with symptomatic carotid stenosis had the highest incidences of non-fatal stroke and death (Cockcroft, n = 19: 21.1%, MDRD, n = 10: 40%).**

Conclusion: **Severe RI is a risk factor for complications after carotid surgery. Creatinine clearance calculated according to the MDRD formula correlates most closely with these complications. Symptomatic patients with severe RI, according to the creatinine clearance, are at high risk with a very high level of postoperative complications. (J Vasc Surg 2010;51:43-50.)**

Stroke is the third most common cause of death in industrialized countries and the principal cause of disability.[1] Stenosis of the carotid artery is one of the principal causes of stroke and is an indication for surgery according to recommendations based on the NASCET (North American Symptomatic Carotid Endarterectomy Trial),[2] ECST (European Carotid Surgery Trial),[3] and ACAS (Asymptomatic Carotid Atherosclerosis Study)[4] studies.

The purpose of this preventive surgery is to reduce the long-term risk of stroke in asymptomatic patients and the risk of stroke recurrence in symptomatic patients. The risk of surgery-related morbidity must be lower than the expected benefits. For this reason, it is important to determine factors associated with morbidity.

Chronic renal insufficiency is one of the factors studied and has been the subject of a number of a publications with contradictory results.[5-13] These studies used different definitions of renal insufficiency (RI). Certain authors used plasma levels of creatinine to define groups of patients,[5,7,8,10,14] others considered that creatinine clearance gave a better assessment of renal function,[1] and others associated the two.[9] Furthermore, different levels were used to constitute the groups. On top of this, the method used to calculate creatinine clearance differed. In most publications, either the Cockcroft-Gault[9] or the Modification of Diet in Renal Disease (MDRD) method was used.[11] It is therefore difficult to compare the results of these studies and to determine the stage of renal insufficiency that may affect the results of carotid surgery.

Our objective was to analyze the influence of renal insufficiency on our results in carotid surgery and to determine which method gave the best correlation with postoperative complications.

METHODS

Study population. We prospectively gathered in a database all of the cases of patients operated on for carotid stenosis in our department from January 1, 2003 to December 31, 2008. The exclusion criteria were the absence of a plasma creatinine dosage on the eve of the operation and dialysis-dependent patients. There were no renal transplanted patients in the current series.

The following data were recorded: patients' characteristics, cardiovascular risk factors, associated comorbidities, neurovascular symptoms, surgical data, and postoperative events up to day 30 (stroke, death, and postoperative myocardial infarction [MI]). In comorbidities, peripheral artery disease (PAD) was defined as symptomatic patients (claudication, critical ischemia) or a history of lower limb surgery (bypass, angioplasty, percutaneous treatment).

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The carotid stenosis was defined as symptomatic if the patient had experienced a neurological ischemic event such as stroke, transient ischemic attack (TIA), or amaurosis fugax in the 6 months before the operation.

MI was defined as the presence of an abnormal electrocardiogram associated with chest pain and/or elevated levels of plasma troponin with a value above the 99th percentile of the upper reference limit.[15]

Carotid surgery was performed under locoregional anesthesia using superficial cervical plexus block, except in the case of patient refusal, or in the case of combined surgery (eg, carotid and heart surgery). During the operation, the cerebral status was monitored by surveillance of the motor function of the contralateral upper limb (grip-strength gauge in the contralateral hand or in both hands in cases of bilateral carotid stenosis > 70%) and surveillance of vigilance at 10-minute intervals throughout the intervention and every 5 minutes while the carotid was clamped. In cases of intolerance to carotid clamping (loss of consciousness, agitation, impaired motor function in the upper limb[s]), a shunt was inserted. Under general anesthesia, a shunt was systematically inserted. Surgery consisted of open carotid endarterectomy followed by patch angioplasty (Dacron or vein) or by a carotid-to-carotid bypass in cases of high bifurcation. All of the patients were systematically on antiplatelets, were checked the day after surgery with an ultrasound examination, using both continuous wave Doppler and Duplex, and were usually discharged the same day.

Definitions of RI: We considered three methods to define RI. To differentiate the groups, we used the levels of creatinine and creatinine clearance reported in the National Kidney Foundation practice guidelines.[16]

- Preoperative level of plasma creatinine:

The patients were put into one of three groups: normal renal function (level of plasma creatinine < 1.5 mg/dL), moderate RI (1.5 mg/dL ≤ creatinine < 3 mg/dL), and severe RI (creatinine ≥ 3 mg/dL).

- Creatinine clearance calculated using the Cockcroft-Gault formula:[17]

Creatinine clearance reflects the glomerular filtration rate (GFR).

The formula used was:

$$\text{GFR (mL/min/1.73 m}^2) = [(140 - \text{age}) \times \text{weight} \times \text{k}]/(\text{creatinine in mg/dL}*72)$$

K = 1 in men and k = 0.85 in women.

- Creatinine clearance calculated using the MDRD formula[18]

The formula used to calculate the GFR was:

$$\text{GFR (mL/min/1.73 m}^2) = 186.3 \times (\text{creatinine in mg/dL})^{-1.154} \times (\text{age})^{-0.203} \times \text{k}$$

k = 1 in men and k = 0.742 in women

For these two methods, patients were put into one of three groups: normal renal function (GFR ≥ 60 mL/min), moderate RI (30 mL/min ≤ creatinine < 60 mL/min), or severe RI (creatinine < 30 mL/min).

Judgment criteria. The endpoints were the incidence of neurological events, MI, and death up to day 30 or during hospitalization in case of prolonged hospital stay. Neurological events included strokes (neurological deficit with cerebral lesion on an emergency magnetic resonance imaging [MRI] or cerebral computed tomography [CT]-scan) or TIA (neurological deficit with no cerebral lesion, and resolved in 24h). Diagnoses were confirmed by a neurologist. The primary endpoint was the 30-day stroke and death rate defined by the incidence of non-fatal stroke and death at day 30.

Statistical analysis. The results are presented as means or medians when the distribution was not Gaussian, and quantitative data as means ± standard deviations [min max]. For each of the definitions of renal insufficiency, the three groups were compared in univariate analyses using the Chi-square test or Fisher's exact test for categorical variables, and analysis of variance (ANOVA) for continuous variables. Comparisons were made with the control group "normal renal function". Results with $P < .05$ were considered significant.

RESULTS

Between January 1, 2003 and December 31, 2008, 971 endarterectomies were performed in 911 patients. Ten patients were excluded from the study because the preoperative level of plasma creatinine was missing. The study thus involved 961 endarterectomies carried out in 901 patients. The proportion of symptomatic stenosis was 25.9% (n = 249), among which there were 43.8% of stroke (n = 109), 38.6% of TIA (n = 96), and 17.7% of amaurosis fugax (n = 44). The operations were performed under locoregional anesthesia in 95.8% of cases (n = 920). In the current series, we performed two combined operations involving carotid and heart surgery (one for coronary artery bypass graft [CABG], one for aortic valve replacement). These two patients had moderate renal insufficiency (creatinine clearance: 55 mL/min and 37.9 mL/min) and recovery was uneventful.

At day 30, 13 patients (1.3%) had suffered from a postoperative neurological event (three TIA, 10 strokes). Six patients recovered completely (after repeat surgery for thrombosis in two cases). The neurological event was the cause of death in three patients. We counted these cases as a stroke and as a death. Four patients kept a minor upper limb deficit. Nine patients (0.9%) died at day 30. Three patients with renal insufficiency (moderate insufficiency according to creatinine level, but severe insufficiency according to creatinine clearances) died from postoperative stroke. Three patients (with normal renal function according to creatinine level, but one normal and two with moderate renal insufficiency according to creatinine levels) died from postoperative cardiogenic shock linked to MI. One patient treated with anticoagulation therapy for su-

Table I. Analysis according to level of plasma creatinine

	Renal function according to plasma creatinine (n = 961)			
	Normal renal function creatinine < 1.5 mg/dL No. (%)	*Moderate renal insufficiency 1.5 mg/dL ≤ creatinine < 3 mg/dL No. (%)*	*Severe renal insufficiency creatinine ≥ 3 mg/dL No. (%)*	P *value*
No. of patients	800 (83.2%)	149 (15.5%)	12 (1.2%)	
Cardiovascular risk factors				
Smoking	463 (57.9%)	81 (54.4%)	8 (66.7%)	.589
Hypertension	600 (75.0%)	126 (84.6%)	10 (83.3%)	.035
Dyslipidemia	478 (59.8%)	77 (51.7%)	9 (75.0%)	.095
Diabetes	223 (27.9%)	41 (27.5%)	5 (41.7%)	.567
BMI > 30	158 (19.8%)	26 (17.4%)	3 (25.0%)	.718
Gender (male)	597 (74.6%)	125 (83.9%)	9 (75.0%)	.051
Age (mean)	71.7 years ± 9.3	76 years ± 7.7	75 years ± 6.0	<.001
Age > 80 years old	170 (21.3%)	48 (32.2%)	2 (16.7%)	.012
Weight (mean)	75 kg ± 13.8	76 kg ± 13.4	78 kg ± 16.0	.520
Medical history				
COPD	25 (3.1%)	8 (5.4%)	0 (0.0%)	.310
Coronaropathy	278 (34.8%)	60 (4.3%)	7 (58.3%)	.115
PAD	181 (22.6%)	56 (37.6%)	5 (41.7%)	<.001
Controlateral occlusion	53 (6.6%)	11 (7.4%)	0 (0.0%)	.750
Symptomatic patients	215 (26.9%)	32 (21.5%)	2 (16.7%)	.294
Stroke	91 (11.4%)	17 (11.4%)	1 (8.3%)	
TIA	84 (1.5%)	11 (7.4%)	1 (8.3%)	
Amaurosis fugax	40 (5.0%)	4 (2.7%)	0 (.0%)	
Surgery				
Peroperative shunt	64 (8.0%)	14 (9.4%)	3 (25.0%)	.980
30-day morbi-mortality				
Neurological event	9 (1.1%)	4 (2.7%)	0 (.0%)	.293
Death	5 (0.6%)	3 (2.0%)	1 (8.3%)	.008
Myocardial infarction	5 (0.6%)	2 (1.3%)	0 (0.0%)	.612
Stroke and death	1.8%	2.7%	8.3%	.210

BMI, Body mass index; *COPD,* chronic obstructive pulmonary disease; *PAD,* peripheral artery disease; *TIA,* transient ischemic attack.
Stroke and death rate: Non-fatal neurological events (TIA or stroke) and death rate.

praventricular dysrhythmia died from cerebral hemorrhage after a fall the evening following the intervention. One patient with severe renal insufficiency died at day 13 from *E. coli* septicemia originating in the digestive tract. Finally, one patient treated with anticoagulants died 72 hours after the intervention from suffocating hematoma. Seven patients (0.7%) suffered MI. The 30-day stroke and death rate was 2%.

Study of renal function according to plasma creatinine. The characteristics of the three groups of patients are presented in Table I. Eight hundred patients (83%) had normal preoperative renal function; 149 patients had moderate RI (16%), while 12 patients (1%) had severe RI.

Patients in the moderate and severe RI groups were older than those in the control group, and PAD was more frequent in the severe RI group ($P < .001$).

The incidence of postoperative neurological events was 1.1% in the control group (n = 9), 2.7% in the moderate RI group (n = 4), and 0% in the severe RI group ($P = .29$). The incidence of postoperative death was 0.6% in the control group (n = 5), 2% in the moderate RI group (n = 3), and 8.3% (n = 1) in the severe RI group ($P = .01$). The incidence of postoperative MI was 0.6% in the control group (n = 5), 1.3% in the moderate RI group (n = 2), and 0% in the severe RI group ($P = .61$).

The stroke and death rate was 1.8% in the control group, 2.7% in the moderate RI group, and 8.3% in the severe RI group ($P = .21$).

Study of renal function using creatinine clearance calculated according to the Cockcroft-Gault formula. The characteristics of the three groups of patients are shown in Table II. Normal preoperative renal function was found in 480 patients (50%), moderate RI was found in 414 patients (43%), and severe RI in 67 patients (7%).

Smoking was less frequent in the moderate RI (46.9%) and severe RI (43.3%) groups than in the control group (68.5%) ($P < .001$). In parallel, the moderate RI and severe RI groups contained a lower proportion of diabetics ($P < .01$) and obese patients ($P < .001$) than did the control group. The use of shunts was greater in the moderate RI (10%) and severe RI (16%) groups than in the control group (6%) ($P < .01$)

The incidence of postoperative neurological events was 1.3% in the control group (n = 6), 0.7% in the moderate RI group (n = 3), and 6% in the severe RI group (n = 4) ($P < .01$). The incidence of postoperative death was 0.4% in the control group (n = 2), 0.7% in the moderate RI group (n = 3), and 6% (n = 4) in the severe RI group ($P < .001$). The incidence of MI was 0.6% in the control group (n = 3), 0.7% in the moderate RI group (n = 3), and 1.5% in the severe RI group (n = 1) ($P = .74$).

Table II. Analysis according to creatinine clearance calculated using the Cockcroft-Gault formula

	Renal function according to creatinine clearance using the Cockcroft formula			
	Normal renal function GFR ≥ 60 mL/min No. (%)	*Moderate renal insufficiency 60 mL/min < GFR ≥ 30 mL/min No. (%)*	*Severe renal insufficiency GFR < 30 mL/min No. (%)*	P *value*
No. of patients	480 (49.9%)	414 (43.1%)	67 (7.0%)	
Cardiovascular risk factors				
Smoking	329 (68.5%)	194 (46.9%)	29 (43.3%)	<.001
Hypertension	346 (72.1%)	334 (80.7%)	56 (83.6%)	<.001
Dyslipidemia	297 (61.9%)	236 (57.0%)	31 (46.3%)	.034
Diabetes	158 (32.9%)	94 (22.7%)	17 (25.4%)	<.001
BMI > 30	134 (27.9%)	47 (11.4%)	6 (9.0%)	<.001
Gender (male)	414 (86.3%)	280 (67.6%)	37 (55.2%)	<.001
Age (mean)	67.5 years ± 8.6	76.9 years ± 6.7	79.8 years ± 7.6	<.001
Age > 80 years old	30 (6.3%)	155 (37.4%)	35 (52.2%)	<.001
Weight (mean)	80.7 kg ± 13.0	70.6 kg ± 12.0	65.0 kg ± 13.6	<.001
Medical history				
COPD	13 (2.7%)	17 (4.1%)	3 (4.5%)	.460
Coronaropathy	165 (34.4%)	151 (36.5%)	29 (43.3%)	.340
PAD	119 (24.8%)	98 (23.7%)	25 (37.3%)	.056
Controlateral occlusion	28 (5.8%)	31 (7.5%)	5 (7.5%)	.740
Symptomatic patients	136 (28.3%)	94 (22.7%)	19 (28.4%)	.143
Stroke	57 (11.9%)	42 (10.1%)	10 (14.9%)	
TIA	49 (10.2%)	39 (9.4%)	8 (11.9%)	
Amaurosis fugax	30 (6.3%)	13 (3.1%)	1 (1.5%)	
Surgery				
Peroperative shunt	28 (5.8%)	42 (10.1%)	11 (16.4%)	<.001
30-day morbi-mortality				
Neurological event	6 (1.3%)	3 (0.7%)	4 (6.0%)	<.001
Death	2 (0.4%)	3 (0.7%)	4 (6.0%)	<.001
Myocardial infarction	3 (0.6%)	3 (0.7%)	1 (1.5%)	.740
Stroke and death	1.7%	1.4%	7.5%	.004

BMI, Body mass index; *COPD,* chronic obstructive pulmonary disease; *PAD,* peripheral artery disease; *TIA,* transient ischemic attack.
Stroke and death rate: Non-fatal neurological events (TIA or stroke) and death rate.

The stroke and death rate was 1.7% in the control group, 1.4% in the moderate RI group, and 7.5% in the severe RI group ($P = .004$).

Study of renal function according to creatinine clearance calculated using the MDRD formula. The characteristics of the three groups of patients are presented in Table III. Normal preoperative renal function was found in 574 patients (60%), moderate RI in 347 patients (36%), and severe RI in 40 patients (4%).

The moderate RI and severe RI groups comprised a lower proportion of smokers ($P < .001$) but more hypertensive patients ($P < .001$) than in the control group. Coronary artery disease or PAD was more frequent in the severe RI group (57.5% and 45%, respectively) than in the other groups ($P < .01$).

Shunts were used more frequently in the severe RI group (25%) than in the moderate RI (8%) and control (7%) groups ($P < .01$).

The incidence of postoperative neurological events was 1% in the control group (n = 6), 0.9% in the moderate RI group (n = 3), and 10% in the severe RI group (n = 4) ($P < .001$). The incidence of postoperative death was 0.3% in the control group (n = 2), 0.9% in the moderate RI group (n = 3), and 10% (n = 4) in the severe RI group ($P < .001$). The incidence of MI was 0.5% in the control group (n = 3), 1.2% in the moderate RI group (n = 4), and 0% in the severe RI group ($P = .48$).

The stroke and death rate was 1.4% in the control group, 1.7% in the moderate RI group, and 12.5% in the severe RI group ($P < .001$).

Fig 1 compares the stroke and death rate in the different groups according to the classification used. For patients with normal renal function, whatever the classification used, the incidence is around 1.7%. For all of the classifications, the stroke and death rate increases with the severity of the renal function impairment but to different degrees. The stroke and death rate in patients with severe RI according to the MDRD classification is 12.5%, whereas it is 7.5% if the Cockcroft classification is used and 8.3% if creatininemia is the yardstick.

One subgroup study was carried out. Within the severe RI groups according to Cockcroft and MDRD, we analyzed the impact of preoperative neurovascular symptoms on the incidence of death and neurological events (Table IV). In these two groups, symptomatic patients were more likely to die after the operation ($P < .01$). Symptomatic patients with severe renal insufficiency according to the MDRD classification were more likely to suffer from postoperative stroke than were asymptomatic patients (30% vs. 3.3%; $P = .04$). Among asymptomatic patients with severe renal insuffi-

Table III. Analysis according to creatinine clearance calculated using the MDRD formula

	Renal function according to creatinine clearance using the MDRD formula			
	Normal renal function GFR ≥ 60 mL/min No. (%)	*Moderate renal insufficiency 60 mL/min < GFR ≥ 30 mL/min No. (%)*	*Severe renal insufficiency GFR < 30 mL/min No. (%)*	P *value*
No. of patients	574 (59.7%)	347 (36.1%)	40 (4.2%)	
Cardiovascular risk factors				
Smoking	360 (62.7%)	172 (49.6%)	20 (50.0%)	<.001
Hypertension	402 (70.0%)	299 (86.2%)	35 (87.5%)	<.001
Dyslipidemia	344 (59.9%)	200 (57.6%)	20 (50.0%)	.411
Diabetes	166 (28.9%)	90 (25.9%)	13 (32.5%)	.501
BMI > 30	116 (20.2%)	63 (18.2%)	8 (20.0%)	.742
Gender (male)	472 (82.2%)	236 (68.0%)	23 (57.5%)	<.001
Age (mean)	70.1 years ± 9.5	75.9 years ± 7.4	76.7 years ± 7.2	<.001
Age > 80 years old	95 (16.6%)	112 (32.3%)	13 (32.5%)	<.001
Weight (mean)	76 kg ± 13.8	74.4 kg ± 13.6	72.6 kg ± 14.1	.109
Medical history				
COPD	19 (3.3%)	13 (3.7%)	1 (2.5%)	.892
Coronaropathy	200 (34.8%)	122 (35.2%)	23 (57.5%)	.014
PAD	128 (22.3%)	96 (27.7%)	18 (45.0%)	<.001
Controlateral occlusion	37 (6.4%)	25 (7.2%)	2 (5.0%)	.521
Symptomatic patients	158 (27.5%)	81 (23.3%)	10 (25.0%)	.370
Stroke	66 (11.5%)	36 (10.4%)	7 (17.5%)	
TIA 64	(11.1%)	29 (8.4%)	3 (7.5%)	
Amaurosis fugax	28 (4.9%)	16 (4.6%)	0 (0.0%)	
Surgery				
Peroperative shunt	42 (7.3%)	29 (8.4%)	10 (25.0%)	<.001
30-day morbi-mortality				
Neurological event	6 (1.0%)	3 (0.9%)	4 (10.0%)	<.001
Death	2 (0.3%)	3 (0.9%)	4 (10.0%)	<.001
Myocardial infarction	3 (0.5%)	4 (1.2%)	0 (0.0%)	.483
Stroke and death	1.4%	1.7%	12.5%	<.001

BMI, Body mass index; *COPD,* chronic obstructive pulmonary disease; *MDRD,* modification of Diet in Renal Disease; *PAD,* peripheral artery disease; *TIA,* transient ischemic attack.
Stroke and death rate: Non-fatal neurological events (TIA or stroke) and death rate.

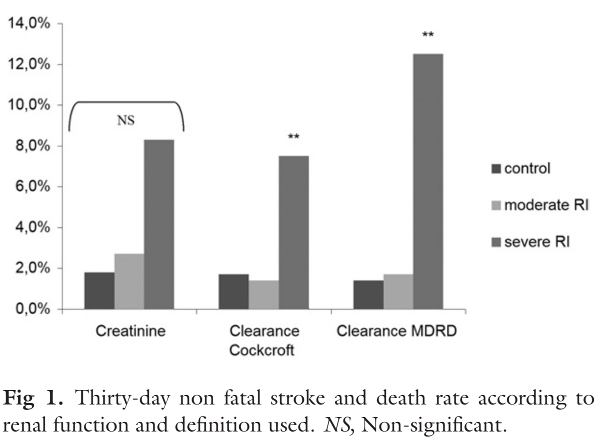

Fig 1. Thirty-day non fatal stroke and death rate according to renal function and definition used. *NS,* Non-significant.

ciency, whatever the classification used, postoperative death was 0%, and the incidence of postoperative stroke was 2.1% (Cockcroft) and 3.3% (MDRD). For all asymptomatic RI patients taken together, the stroke and death rate was 2.1% and 3.3% according to the Cockcroft and MDRD classification, respectively. The stroke and death rate in symptomatic severe RI patients was significantly higher: 21.1% for the Cockcroft classification ($P = .02$) and 40% for the MDRD classification ($P = .01$).

DISCUSSION

In the light of these results, it appears that renal insufficiency has an impact on the results of carotid surgery. The incidence of postoperative complications correlates with the severity of the renal insufficiency. By analyzing the incidence of complications according to renal function assessed using three different classification methods, we were able to show the impact of RI depending on the classification method used. RI assessed using MDRD creatinine clearance gives the highest incidence of complications and probably provides the best indication of the gravity of this disease. It also appears that the presence of preoperative neurovascular symptoms in these patients must be taken into account when deciding whether surgery is indicated. Therefore, although it is appropriate to consider carotid surgery in asymptomatic RI patients, whatever the severity of RI, the operation may be inappropriate in patients with severe RI and symptoms of neurovascular disease. Indeed, the incidence of complications in this group of patients is far higher than the maximum recommended in the literature,[2-4,19,20] and the expected benefits of the operation are outweighed by the severe morbidity.

Several studies have tried to define the relationship between RI and the complications of carotid surgery.

Table IV. Impact of preoperative neurological symptoms in patients with severe RI

	Severe RI according to Cockcroft			*Severe RI according to MDRD*		
	N = 67			*N = 40*		
Stroke/death rate	7.5%			12.5%		
	Asymptomatic	*Symptomatic*	P *value*	*Asymptomatic*	*Symptomatic*	P *value*
No. of patients	48 (71.6%)	19 (28.4%)		30 (75.0%)	10 (25.0%)	
30-day morbi-mortality						
Neurological event	1 (2.1%)	3 (15.8%)	.075	1 (3.3%)	3 (30.0%)	.041
Death	0 (0.0%)	4 (21.1%)	.005	0 (0.0%)	4 (40.0%)	.002
Stroke/death rate	2.1%	21.1%	.021	3.3%	40%	.012

MDRD, Modification of Diet in Renal Disease; *RI,* renal insufficiency.

Rigdon et al[5] analyzed the interest of assessing risk using plasma creatinine for 285 interventions in 237 patients. For the combined endpoint of postoperative stroke and death, they found an incidence of 43% in the severe RI group (n = 7, creatinine > 2.9 mg/dL) compared with 7% in the control group (n = 264, creatinine < 1.5 mg/dL) ($P < .001$).

In 497 patients separated according to the level of creatininemia < 1.8 mg/dL (n = 448) or > 1.8 mg/dL (n = 49), Ayerdi et al[14] reported an incidence of MI of 5.4% and 28.6%, an incidence of postoperative stroke of 2.7% and 2.0%, and mortality of 0.9% and 8.2%, respectively, thus confirming the negative impact of RI on the results of carotid surgery.

Reil et al[7] reviewed 370 endarterectomies with regard to RI defined by creatinine > 1.5 mg/dL and found no difference between the groups for postoperative stroke and death.

Reed et al[21] reported 1370 endarterectomies and analyzed different suspected risk factors including RI. There was no difference between the RI group defined by creatinine > 2 mg/dL and the control group with regard to postoperative stroke and death.

Ascher et al[8] analyzed 675 interventions in 609 patients, 166 patients with RI (creatinine > 1.5 mg/dL), and 443 control patients. There was no difference between the groups for postoperative strokes (1.2% in the RI group vs 0.5% in the control group). Mortality, however, was 3% in the RI group and 0% in the control group ($P < .002$). Subgroup analysis of patients with renal insufficiency showed a mortality of 0.7% in patients with moderate RI (creatinine < 2.9 mg/dL) and 17% in cases of severe RI (creatinine > 3 mg/dL) ($P < .001$). In patients with creatinine > 3 mg/dL, mortality in symptomatic patients was greater than that in asymptomatic patients, but the difference was not significant (28% vs 13%, $P = .6$). The authors recommended not proposing carotid surgery to patients with severe RI.

Tarakji et al[10] reviewed 1351 interventions, separating patients with renal insufficiency into two groups: moderate RI and severe RI (creatinine thresholds: 1.5 mg/dL and 3 mg/dL, respectively). The incidence of a combined endpoint postoperative stroke and death was 9% for all RI together (n = 143) (7.3% in moderate RI, 19% in severe RI) and 2.6% in the control group (n = 150) ($P < .05$).

Debing et al[9] analyzed the impact of renal function for 1011 endarterectomies in 857 patients classified into RI patients (n = 102, creatinine ≥ 1.5 mg/dL and creatinine clearance ≤ 30 mL/min) and a control group (n = 909). The incidence of postoperative death was higher in the RI group than in the control group (3.9% vs 1%, $P = .013$).

The largest study was that done by Sidawy et al,[11] who used the Veterans Affairs Medical Center database to analyze the results of 20,899 carotid endarterectomies. Renal function was assessed using creatinine clearance calculated using the MDRD formula, and patients were separated into moderate RI (n = 6423, GFR 30 mL/min/1.73 m^2-59 mL/min/1.73 m^2) and severe RI (n = 511, GFR < 30 mL/min/1.73 m^2). The two groups were matched for neurovascular symptomatology, but symptomatic patients were defined as those who had had preoperative stroke or TIA, whatever the time between the symptom and the operation. There was a significant difference between the groups for postoperative stroke (control 1.7%, moderate RI 1.9%, severe RI 2.7%). The incidence of heart complications (MI or cardiac arrest) was highest in the moderate RI group ($P < .001$). This was found in our study, but the relationship was not significant. Severe RI patients presented higher mortality rates (3% vs control 1%, $P < .001$).

Our results are in keeping with the above, and we also showed that RI, especially when creatinine clearance calculated by the Cockcroft or MDRD formula was below 30 mL/min/1.73 m^2, was an independent risk factor for postoperative complications.

The negative impact of RI has also been highlighted in other types of surgery, especially heart[22,23] and subrenal aortic surgery for which it has been shown that creatinine clearance was a stronger predictor of complications than was plasma creatinine alone[24] and for lower extremity bypass surgery.[25]

Several factors may explain the higher incidence of postoperative complications in patients with renal insufficiency. Cardiovascular disease is the principal cause of death in patients on dialysis.[26] There is a relationship between RI and heart failure, called the *cardio-renal syndrome*, which is responsible for excess morbidity.[27] In a population of English men with moderate renal insufficiency, there was an excess risk of stroke of 60% and a correlation between the incidence of MI, stroke, and death caused by cardiovascular disease that was proportional to the level of plasma creatinine.[28]

The terms *calciphylaxis* or *calcifying uremic arteriolopathy* were proposed to describe more precisely a rapidly progressive form of calcification of the tunica media in patients with renal insufficiency.[29] The negative impact of RI on the results of carotid surgery probably stems from diffuse microangiopathic lesions caused by RI, which lead to postoperative MI, or the failure of limb revascularization in PAD.[30]

In this study, we have shown that analysis of the results following carotid surgery may vary depending on the method used to assess renal function. Our objective was not to determine what value best reflects true renal function but rather what value is the best predictor of postoperative complications. It appears that plasma creatinine is not only a poor predictor of renal function,[11] as it depends on a number of factors (age, gender, race, method of measurement), but it is above all a poor predictor of postoperative complications.

The results reported in Table IV concerning severe RI patients raised several questions: the postoperative complication rate is tremendously high in the symptomatic group and surprisingly low in the asymptomatic group. Two criticisms can be stated here. First, none of the groups had a "medical-alone" control group to be compared with (ie, what is the risk of stroke in symptomatic as well as asymptomatic patients with severe carotid stenosis and severe RI who are not operated on?). So, is difficult to draw any conclusions about the indications for surgery in these specific cases. Second, the small number of patients in each group is a source of error. The only published data concerning a large number of patients came from the VA study and showed that a history of stroke or TIA before CEA was an independent predictor of increased neurologic events and death. The subgroup "symptomatic stenosis and severe RI" was not specifically studied in the VA series. Therefore, the data shown in Table IV need to be confirmed in a larger group of patients, which may address the question as to whether or not this high-risk subgroup would benefit from surgery. Subsequently, carotid artery stenting could be tested as an alternative to surgery in this population.

CONCLUSION

We have shown that RI defined by creatinine clearance calculated according to the MDRD formula correlates most strongly with the risk of postoperative complications following carotid surgery. Patients with symptomatic carotid stenosis and severe RI present a very high risk of postoperative complications, and the interest of preventive carotid surgery in this group of patients needs to be considered very carefully.

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